Section Preview of the Teacher's Edition for

Science and Sustainability, Revised Edition

Activity 31

Suggested student responses and answer keys have been blocked out so that web-savvy students do not find this page and have access to answers.

To experience a complete activity please request a sample through the link found in the footer at www.lab-aids.com

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SEPUP®
Issue-Oriented Science

Fueling Trade-offs

31

Activity Overview

4
40- to 50-minute sessions

Summary

As a society, we use a variety of fuels to supply the energy needed for transportation, industrial processes, electricity generation, and heat. In this activity, students compare two liquid fuels, ethanol and kerosene. They determine the amount of energy generated by burning each fuel. Students examine the trade-offs involved in using each of these fuels for transportation and consider the use of other alternative energy sources. Finally, students explore combustion as a chemical reaction and perform calculations that reinforce the concept of conservation of mass during chemical reactions.

Teacher's Note: In this part of the course, information about energy in many forms and from many sources is surveyed and investigated. How this energy is used and the trade-offs involved in its use are also explored. These investigations are meant as introductions, not as exhaustive studies. Many of these topics are the focus of year-long courses in themselves and are introduced here only to provide students with a base level of information from which to begin assessing the relevance of energy use and production to their lives.

Goals

1. Observe combustion reactions and calculate the amount of heat produced by burning a fuel. (DESIGNING INVESTIGATIONS)
2. Compare the advantages and disadvantages of different fuels. (EVIDENCE AND TRADE-OFFS)
3. Investigate the chemistry of combustion reactions. (UNDERSTANDING CONCEPTS)
4. Investigate incomplete combustion and the production of carbon monoxide. (UNDERSTANDING CONCEPTS)

Teaching Summary

Session One (31.1)

1. Teacher introduces combustion and fuel choice.
2. DI Students design an investigation to measure the amount of energy released during the combustion of kerosene and ethanol.

Session Two (31.1)

3. Students measure the amount of energy released during the combustion of kerosene and ethanol.

Session Three (31.1 / 31.2)

4. AD Class discusses results of the combustion experiment.
5. ET Students consider the attributes of an "ideal" fuel.

Session Four (31.3)

6. Students are introduced to the chemistry of combustion reactions.
7. Class discusses the role of chemical structure in determining the energy of combustion.

Advance Preparation

Session One

Fill four of your fuel burners with about 30 mL of kerosene and fill the other four with about 30 mL of alcohol. The combustion of kerosene in the fuel burners produces smoke and other fumes. Before performing Activity 31.1 with your students, light two or three of the kerosene-filled burners in your classroom and allow them to burn for five minutes. Check to see that there is adequate ventilation to prevent the accumulation of smoke and fumes in the classroom.

Since students have conducted similar investigations that involve calculating the energy produced from combustion reactions, this session asks them to design their own investigation. If you decide this is inappropriate or impractical for your students, prepare a copy of Student Sheet 31.1, "How Much Energy Is There?" for each student. In this case, you may skip Teaching Procedure Step 2.

Advance Preparation (cont.)

Ask each student to bring in a standard-sized (355-mL / 12-oz) aluminum soda can.

Construct molecular models of kerosene and ethanol. See the structural formulas in Figure 1 on page 797 of this Teacher's Guide. You will use these models during Sessions One, Three, and Four.

Future Activities

Activity 35

Activity 35, "Mechanical Energy," requires the use of many items not provided in the equipment kit for *Science and Sustainability*. Most of these items can be found in a high school physics lab. You may want to look ahead and arrange to borrow these materials from your school's physics teacher(s).

Materials

Session One (31.1)

For the teacher

1 60-mL bottle of ethanol
1 480-mL bottle of kerosene
1 molecular model set (see Advance Preparation)

Session Two (31.1)

For the teacher

Transparency 31.1, “Class Data From Activity 31.1” (optional)
* transparency markers
* overhead projector
* 1 can holder (optional; see Figure 2)

For the class

supply of room-temperature water

For each group of four students

1 glass fuel burner containing either ethanol or kerosene (lamp oil)
* 1 can holder (see Figure 2)
* 1 immersion thermometer
* 1 book of matches
* 1 balance
* 1 100-mL graduated cylinder
* 1 metric ruler
* access to a clock with a second hand

For each team of two students

* 1 aluminum soda can
* 1 calculator (optional)

For each student

* 1 pair of safety glasses
Student Sheet 31.1 a–d, “How Much Energy Is There?” (optional)

**Not supplied in kit*

Materials (cont.)

Session Three (31.1 / 31.2)

For the teacher

Transparency 31.1, "Class Data From Activity 31.1," with class data from Session Two (optional)
Transparency 31.2, "Comparison of Fuel Properties"
Transparency 31.3, "Some Common Fuels" (optional)
* blank transparency
* transparency markers
molecular models of ethanol and kerosene
* overhead projector

Session Four (31.3)

For the teacher

molecular models of ethanol and kerosene

For each team of two students

1 molecular model set

**Not supplied in kit*

Links

To sustainability

The ability to provide energy in a sustainable way is necessary to our efforts to raise or maintain the quality of life for people today and in the future. Sustainable energy production and use do not deplete resources needed for future generations and do not cause serious environmental damage.

To the last activity

In Part 3, students investigated the extraction and use of material resources, including petroleum, which is an important energy source. In the previous activity, students considered proposals to the World Bank, one of which involved building a pipeline to supply fuel for electricity generation. The issues involved in this type of decision will be explored more fully in this activity and the rest of Part 4.

Links (cont.)

To the next activity

In the next activity, students investigate in more detail the way energy is involved in some chemical interactions. These explorations serve to introduce concepts important for understanding how chemical fuels are used to generate energy.

To technology

Many people believe that today's concerns regarding energy resources and sustainability will be answered by the development of new technologies. This possibility is raised in discussions in the classroom, and energy technologies currently in development are identified and described.

To literacy

In the reading in Activity 31.2, students are introduced to currently available energy sources that are not based on fossil fuels. This reading draws on students' experiences with combustion and chemical reactions in the laboratory. Additionally, Extension 3 provides an opportunity for students to do outside research that will develop their ability to use written information in a practical setting.

Key Concepts

1. Combustion is a chemical reaction between oxygen and a fuel. Most fuels are carbon-based.
2. Different compounds release different amounts of energy when they combust.
3. The amount of energy released during combustion is related to the chemical composition and structure of the material being combusted.
4. Equations for combustion reactions are generally written with the assumption that enough oxygen is present to allow the reaction to proceed to completion. In actual practice, most combustion reactions are not complete, resulting in additional reaction products, such as carbon monoxide (CO).
5. In choosing an appropriate fuel there are trade-offs between energy content, cost, environmental impact, and convenience.

Key Vocabulary

combustion
incomplete combustion
carbon monoxide
alternative energy sources

Resources

Fullick, Patrick, and Mary Ratcliffe, eds. "Should We Invest in Ethanol as the Future Fuel?" in *Teaching Ethical Aspects of Science*. Southampton, UK: The Bassett Press, 1996.

Wang, Michael, Christopher Saricks, and Dan Santini. "Greenhouse Gas Emissions of Fuel Ethanol Produced From Corn and Cellulosic Biomass." EM: *Air and Waste Management Association's Magazine for Environmental Managers,* October 1999, pp. 17–25.

Background Information

Ethanol as a Fuel Additive

In Activity 32, "Fuel From Food," students will have the opportunity to investigate the production of ethanol from corn. In this activity, they compare the combustion of ethanol to that of kerosene. Ethanol (ethyl alcohol or grain alcohol) is a flammable, colorless liquid with an odor typical of alcohols. Both ethanol molecules and gasoline molecules contain hydrogen and carbon atoms, but ethanol also contains oxygen atoms, which make it a cleaner-burning fuel than gasoline. Ethanol can be produced either synthetically, from petroleum-derived ethylene, or biologically, from grains, agricultural wastes, or any organic material containing starch or sugar. Because ethanol can be produced from annual crops, it is classified as a renewable fuel. Whether or not ethanol production is truly renewable or sustainable depends on the methods used to grow the crops from which it is made and the processes used to make fuel from the crops. In the U.S., ethanol is derived mainly from corn, one bushel of which (~ 25 kg) can produce about 10 L of ethanol. Useful by-products of the conversion of 1 bushel of corn to ethanol include approximately 5.5 kg of 21% protein feed, 1.5 kg of 60% gluten meal, 0.7 kg of corn oil, and 7.5 kg of carbon dioxide (for carbonated soft drinks). Pure ethanol is subject to federal liquor laws and taxes, but additives are mixed into ethanol fuel to "denature" it, making it unfit to drink and therefore exempt from liquor taxes.

Under the Energy Policy Act of 1992 (EPACT), the secretary of energy is required to "ensure the availability of those replacement fuels that will have the greatest impact in reducing oil imports, improving the health of our Nation's economy, and reducing greenhouse gas emissions." According to EPACT, alternative fuels include ethanol and other alcohols, mixtures containing 85% or more alcohol by volume, hydrogen, fuels other

Background Information (cont.)

than alcohols derived from biological materials, and any other fuel the secretary of energy determines is substantially not petroleum. Alcohol fuels, particularly ethanol blended with gasoline, are well-suited for replacing gasoline in certain types of vehicles. Methanol (also known as methyl alcohol, wood alcohol, or CH_3OH), although similar to ethanol, has some properties that are quite different, and it cannot be used interchangeably with ethanol in the same engines.

Currently, in some regions, 10% ethanol (by volume) can be added to gasoline to increase the octane rating and to provide oxygen to decrease tailpipe emissions of carbon monoxide. This fuel blend, called gasohol by the public and E10 by the industry in the U.S., is an accepted vehicle fuel.

New vehicle technologies have been developed that can achieve reliable, low-emission operation using fuel blends containing ethanol concentrations much higher than 10%. Some gasoline is needed to make the vehicle easier to start in cold weather and to increase the vehicle's range. These new "flexible-fuel" vehicles can operate on blends of up to 85% ethanol (E85). E85, commonly called fuel ethanol, is 85% denatured ethanol blended with 15% hydrocarbons. One gallon of E85 provides as much energy as 0.72 gallon of gasoline. E100 is 100% denatured ethanol. Other oxygenated fuels have been developed and used in the United States, as further discussed in Activity 32.

In general, the type of emissions produced by vehicles using E85 is similar to emissions from gasoline-powered vehicles, but the quantity of emissions is lower. The quantity of pollutants released into the atmosphere depends on how well the vehicle's emissions control system captures and burns emissions to prevent their release and how well the engine is designed and "tuned" for using fuel ethanol. The emissions control systems found on ethanol-powered vehicles manufactured today have been engineered to meet or exceed all federal and state regulations.

Early reports indicated that the distillation of corn to make ethanol may consume as much energy as is contained in the ethanol. However, recent research has shown that producing ethanol from corn creates 24% more energy than the distillation process uses. In addition, ethanol, like electricity, is useful for purposes that the energy used to produce it is not. Ethanol produced from corn and other feedstocks has the potential to replace a significant amount of petroleum.

Teaching Procedure

Session One (31.1)

1. Introducing combustion and fuel choice

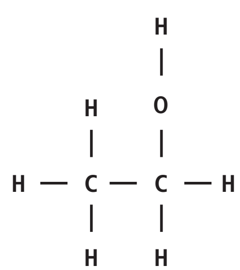
Display two bottles, one containing ethanol and the other containing kerosene. Identify each liquid. Ask the class if anyone knows of any differences or similarities between these two liquids. Accept all answers. Make sure the following points are mentioned: Both liquids burn, both are used as fuels, both contain hydrogen and carbon atoms, ethanol is produced from plants, and kerosene is produced from crude oil. Students may bring up the chemical structure. Hold up the molecular models of ethanol and kerosene you have made, as shown in Figure 1 (see Advance Preparation). Explain that the model shows a typical kerosene molecule but that kerosene is actually a mixture of hydrocarbons containing 11–13 carbon atoms. Kerosene molecules are mostly branched or straight chains, though ring structures (less than 1%) are possible.

Ask the class, *What happens when something burns?* If no one volunteers the information, explain that burning is a chemical reaction called combustion. Combustion generally involves the reaction of a fuel with oxygen. Students may remember the chemical reaction for respiration, discussed in Activity 16, "Photosynthesis." Combustion reactions are very similar to respiration reactions but can occur with many different fuels.

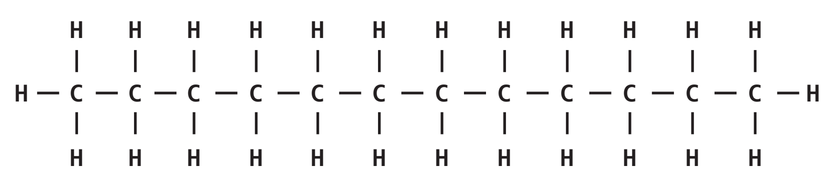
Ask each student group to take five minutes to brainstorm about the following question: *If you were designing a car or a stove and were trying to decide which fuel your design would use, what would you want to know about the different fuels you were considering?* After 5–10 minutes have elapsed, have each group report its discussion. Compile a master list of all answers. Suggestions will most likely include cost, convenience of use, current and future availability, safety, pollution, ease of transportation, and how much energy a set amount of fuel contains and can deliver.

Ask students to turn to Activity 31.1, "How Much Energy is There?" and read the Purpose and Introduction. Have them respond to the Prediction question about which fuel—ethanol or kerosene—they think will produce more heat. Encourage them to use evidence about the chemical structures to explain their ideas.

Figure 1 Structural Formulas for Ethanol and Kerosene



ethanol



kerosene

2. Designing an investigation to measure the amount of energy released during combustion

Ask students to recall Activity 1.3, "Burn a Nut," in which they compared the energy released from the combustion of a nut and from the combustion of kerosene. In Activity 31.1, students are asked to use a similar procedure but to determine the energy released more precisely. If necessary, have them turn to page 10 in their Student Book to review the apparatus used in Activity 1.3. Also remind them of the calculations they did in Activity 4.1, "Are You in Hot Water?" to determine the energy transferred to a sample of water. Encourage them to write a detailed description of how they will now measure the energy released from the combustion of a liquid fuel.

Once students have come up with their ideas of how to do the investigation, it may be useful to discuss with the class as a whole some methods for reducing experimental error. You may want to bring up the following points:

- Students are trying to measure the heat generated during combustion by transferring that heat to water, then measuring the energy gained by the water. Any energy released by the fuel that is not transferred to the water results in experimental error. To reduce this error, students may wish to use a large metal can or other shield placed around the burner to decrease the amount of heat lost to the air.
- Another source of error is the measurement of the temperature of the water. If each trial begins with water of approximately the same temperature, the measurements for determining the change in temperature will be more accurate.
- Some students may suggest using ice water in the cans to make sure that the water is always at roughly the same temperature. However, since melting ice requires additional energy, the liquid water in a can containing ice will not change in temperature as much as liquid water in a can without ice. Using ice introduces a new source of error. This topic was explored more fully in Activity 28.3, "Frigidly Steamy."
- As students are heating the cans, some of the cans may become covered in soot. Some energy can be transferred to the soot, and this can increase error. If possible, cans covered in soot should be replaced with clean cans.
- Finally, if time permits, it is generally a good idea to repeat each trial a number of times so the data can be averaged. Averaging the data will also help reduce error.

DI **Homework:** If your students will use the procedures they have developed, have them make a complete written version to use for this investigation. Explain how these procedures will be assessed. You may want to use the DESIGNING INVESTIGATIONS Scoring Guide in Appendix B.

Session Two (31.1)

3. Measuring the amount of energy released during the combustion of kerosene and ethanol

Before having students carry out the experimental procedure they wrote, stress the safety precautions and review relevant safety procedures. Demonstrate the technique of extinguishing a lit burner by carefully placing the metal cap over the wick. Have students adjust each wick so that it barely projects beyond its metal casing. If the wick is too long, the flame—particularly the kerosene flame—will be extremely large. If necessary, demonstrate or have on display the set-up shown in Figure 2 for suspending the can over the burner.

Figure 2 Experimental Set-up for Activity 31.1

Safety Note: Exercise extreme care when using an open flame in the classroom. Be sure your students know how to extinguish the burner and where to find a fire blanket or fire extinguisher to put out any accidental fires. Students must wear safety glasses during this activity, keep long hair tied back, and wash their hands before leaving the lab.

Point out that half the burners contain kerosene and the other half contain ethanol. Once a group has finished testing their first fuel, they will need to exchange their fuel burner with a group that has already tested the other fuel type. Encourage students to get started so that they will have enough time to test both fuel types.

If your students are using the Procedure on Student Sheet 31.1, point out that each group of four will perform three trials on their fuel for a period of five minutes each, then exchange their fuel burner with a group that has already tested the other fuel type. Emphasize that students will get more accurate results if, after each trial, they carefully pour out the warmed water and allow the can to cool before adding new room-temperature water to the can for the next trial. The combustion of kerosene in the alcohol burners produces smoke. If you have enough cans, you may want the teams testing the kerosene to use a different aluminum can for each trial. Discuss with students why you are suggesting that they use a different can for each kerosene trial—the soot not only creates a problem with cleanliness, but also introduces an additional variable that could affect the experimental results. Use this point to reemphasize the importance of controlling the variables in each trial.

Teacher's Note: Values for the density of kerosene and ethanol given in Table 2 on Student Sheet 31.1d were obtained from the *Handbook of Chemistry and Physics*. Measurements made using the lamp oil (kerosene) and denatured ethanol provided in the *Science and Sustainability* equipment kit are slightly different: kerosene=0.77 g/mL, and ethanol=0.80 g/mL.

Encourage students to begin work. Circulate among the groups and assist as needed. As groups finish their experimental work and begin the calculations, you may need to help some students. As students are ready, use Transparency 31.1, "Class Data Table from Activity 31.1," or a similar table to collect the results from each group for use during the discussion in Session Three.

Homework: Have students complete the reading in Activity 31.2 and answer the Individual Analysis Questions.

Session Three (31.1 / 31.2)

4. Discussing results of the combustion experiment

As necessary, go over the calculations with students. The Procedure Steps on Student Sheet 31.1, Part B, are used here as a guide for this discussion. Whether or not your students wrote their own procedure, they need to perform calculations similar to those shown here. These calculations are necessary for discussing the Group Analysis Questions in Activity 31.1.

Part B Procedure Steps (Student Sheet 31.1)

1. *For each of the two fuels, calculate*
   - *a. the change in water temperature during each trial.*
   - *b. the average change in water temperature.*
   - *c. the mass of fuel consumed during each trial.*
   - *d. the average mass of fuel consumed.*
2. *Record the results of your calculations in the appropriate data table.*
   Ask each student group to share the data they collected for each fuel. Average data from the SEPUP lab are shown in Table 1.
3. *Prepare a third data table similar to Table 2, Use the averages you calculated in Step 1 to complete the calculations needed to fill in the new table.*
   Note: Cp water (specific heat of water) = 1.00 calorie / g•°C.
   Have student groups share the data they collected and entered into the third data table. If you did not do it during Session Two, compile the class data using Transparency 31.1. Data from the SEPUP lab are shown in Table 2.

Table 1 Average SEPUP Data for Combustion of Kerosene and Ethanol

	Kerosene	Ethanol
Mass of fuel combusted (g)		
Initial water temperature (°C)		
Final water temperature (°C)		
Change in water temperature (°C)		

Table 2 SEPUP Data for Comparison of Two Fuels

	Kerosene	Ethanol
Mass of fuel combusted (g)		
Density of fuel (g/mL)	0.82	0.79
Average volume of fuel combusted (mL)		
Average energy absorbed by the water (cal)		
Average energy content of fuel (cal/g)		
Average energy content of fuel (cal/mL)		

As necessary, review how to do the calculations, described below:

Volume

If necessary, remind students that the density (D) of a material is equal to its mass in grams (g) divided by its volume in milliliters (mL):

$$\text{Density (g/mL)} = \frac{\text{mass (g)}}{\text{volume (mL)}}$$

To find the volume of the ethanol or kerosene burned, have students first rearrange the equation

$$\text{volume (mL)} = \frac{\text{mass (g)}}{\text{density (g/mL)}}$$

so that it can be more easily solved for volume:

In standard reference tables, the units of density, though essentially equivalent, may vary. A milliliter is equivalent to a cubic centimeter (cm^3 or cc), therefore density may be presented as grams per mL or as grams per cm^3 (or cc).

Average Energy

The equation given on Student Sheet 31.1 is essentially the same as the equation used in Group Analysis Question 3 in Activity 4.1, "Are You in Hot Water?":

$$\text{energy} = \text{mass water} \bullet \Delta T \text{ water} \bullet \text{Cp water}$$

where the mass of the water is in grams, ΔT (change in temperature) of the water is in ºC, and the Cp (specific heat) of water is 1.00 calorie / g • ºC or 4.2 J / g • ºC. Ask each student to keep a record of the discussion for use in answering the Individual Analysis Questions.

Group Analysis Questions (31.1)

1. ***The results of any experiment may be affected by a variety of errors. Errors can often account for variations in data. Identify some potential sources of error in this experiment that may have affected your results.***

   Ask students to compare their results with those of others in the class and suggest reasons why everyone's results are not the same. Some potential variables affecting results include

   If you feel it appropriate, this question can form the basis for a general discussion of error in scientific procedures or of the concepts of accuracy and precision. Determinate errors (also known as systematic errors) usually have a definite, identifiable source and can cause results from repeated trials to be consistently off from the true value. Determinate errors affect the accuracy of the experimental data. For example, in this investigation, determinate errors could be caused by an inaccurately calibrated scale or thermometer.

   Indeterminate errors are random and thus cause results from repeated trials to yield an average that is close to the true value. Indeterminate errors affect the precision of the data. Gross errors are occasional large-scale, unique events that can cause results far different from the average or expected result. The way an individual reads a thermometer or scale can produce indeterminate or gross errors. Careful scientific procedures can minimize the occurrence of many indeterminate errors and gross errors; this is not the case for determinate errors.

2. ***The energy content of a fuel can be measured as the amount of energy per mass (cal/g or J/g) or the amount of energy per volume (cal/mL or J/mL). Which of these measures of energy content do you think is more useful when comparing fuels? Explain your reasoning.***
   Discuss students' ideas, and then project Transparency 31.2, "Comparison of Fuel Properties." Point out that the standard unit, calories per gram, is more directly related to the underlying molecular structure of the fuel and is unaffected by temperature or the state of the fuel. This does not, however, mean that cal/g is more useful than cal/mL, as will be seen in the next question.

Give students time to work on the Individual Analysis Questions, and then discuss their answers.

Individual Analysis Questions (31.1)

3. ***Gasoline is chemically very similar to kerosene. How could the results of this experiment affect your decision to buy fuel for your car that contains ethanol rather than pure gasoline?***
   When discussing this question, students

AD

4. ***If you were considering the use of one of these fuels for your car, what other information would you like to have before deciding which to use?***
   Students may raise issues such as

AD

It is important for students to realize that their information is limited. In fact, different information sources may disagree about the "facts." Be sure to discuss how students could obtain accurate information, which is an essential ingredient of scientific literacy. Help students understand that all choices we make are based on the information we have as well as on our social, political, and economic circumstances. For example, the economic decision to buy kerosene or ethanol requires a knowledge of current prices. You might call your local hardware store to find costs per gallon of each fuel. In 1999, the average price of ethanol in the U.S. was approximately twice that of kerosene, although the price differential can vary considerably from region to region. Students can also calculate the cost of a fuel based on the number of calories obtained per dollar of fuel. How would this information influence their decision? Tell them that cars vary in efficiency, but a normal car is approximately 14% efficient in burning fuel—that is, only 14% of the energy contained in the fuel is actually transformed into motion by the car's engine.

Have students consider other information they might wish to know before making such a decision, such as the products of combustion. If alcohol were the fuel that produced the least amount of pollution, would it make more sense to burn it, considering the cost? Also have students consider how the renewability of the fuel would affect their decision.

5. Considering the attributes of an "ideal" fuel

Ask individual students to summarize and briefly discuss each of the alternative energy sources covered in the reading in Activity 31.2, "Fuels for the Future." This reading was assigned for homework at the end of Session Two. Then ask each student group to discuss its responses to the Individual Analysis Questions for Activity 31.2. Before holding a full class discussion of the Analysis Questions, ask students if they know of any fuel sources not included in the reading. Briefly discuss any additional fuel sources suggested.

Individual Analysis Questions (31.2)

1. ***List the characteristics of an ideal energy source for use in vehicles. What energy source has characteristics most similar to those you listed?***

   Have students share with the class the items on their lists. Compile a master list on a blank transparency.

   Next, ask each group of four stu-dents to rank the importance of each item on the list. This should take about 10 min-utes. Ask each group to report its rankings, and add each group's rankings to the master list. Lead a discussion/debate about the rankings to bring out the most important issues regarding fuel and energy use. You could group these issues into the following categories: physical properties (e.g., liquid vs. gas, health/safety risks), environmental considerations (e.g., pollution, habitat destruction), economic considerations (e.g., fuel cost, dis-tribution infrastructure), and political con-siderations (e.g., public perception, import/export considerations). Make sure that each of these categories is discussed, and empha-size the importance of considering trade-offs when making decisions that affect many dif-ferent aspects of society. You may wish to display Transparency 31.3, "Some Common Fuels," and discuss some of the possible fuels listed.

2. ***What characteristics would you look for in the ideal source of energy for generating electricity? Which of the energy sources discussed in the reading has characteristics most similar to those you described?***

   Student answers will vary. Insist that students provide reasons for their answers, including relevant scientific and technical evidence. Emphasize the need to consider the same types of issues as those raised in the previous Analysis Question.

3. Fossil-fuel combustion is currently used to produce a large percentage of our electricity. Compare the characteristics of the energy source you chose in Analysis Question 2 to those of fossil-fuel combustion. Explain the trade-offs that should be considered when deciding whether to build an electricity-generation facility that consumes fossil fuels or one that uses your chosen energy source. Ask

ET several students to share their responses.

4. Which of the alternative sources of energy pre-sented in this reading do you think provides energy in the most sustainable way? Why is this energy source not more widely used?Explain your reasoning.

Ask students to share their responses, and encourage other students to comment on each response. Emphasize that there is not one correct answer—different energy sources will be better suited for different geographical regions.

To add another dimension to the discussion, remind students of the discussion of efficiency from Analysis Question 4 in Activity 31.1. As discussed in the answer to that question, in a typical car, less than 20% (generally about 14%) of the energy contained in the fuel that is consumed is used to make the car move; the rest is lost as heat or incompletely combusted gases. Ask students how this information influences the need to develop alternative fuel sources. Efficiency will be investigated more thoroughly in Activity 35.

End by asking, *Do you think that an ideal energy source will ever be discovered?* Discuss student ideas.

Session Four (31.3)

6. Introducing the chemistry of combustion reactions

Hold a brief discussion on combustion, which is defined as the chemical reaction of an element or compound with oxygen that releases energy in the form of heat. Combustion reactions of hydrocarbon and carbohydrate compounds also produce carbon dioxide and water. In the ideal case (complete combustion of a pure hydrocarbon or carbohydrate compound with pure oxygen), carbon dioxide and water are the only products. In typical, non-ideal conditions, the fuel compounds are not pure and the oxygen is supplied by the surrounding air, which contains about 78% nitrogen gas. These other substances cause the production of ash and gases other than CO_2 and H_2O, including oxides of nitrogen and sulfur. In many cases, there is not enough available oxygen for complete combustion; incomplete combustion creates additional products. Incomplete combustion of hydrocarbon and carbohydrate compounds leads to the production of carbon monoxide (CO). Equations 1 and 2 describe the complete combustion of pure ethanol and pure kerosene, the two fuels students explored in Activity 31.1.

Equation 1 Chemical Equation for the Complete Combustion of Ethanol

C_2H_5OH	+	$3O_2$	→	$2CO_2$	+	$3H_2O$
ethanol		oxygen		carbon dioxide		water

Equation 2 Chemical Equation for the Complete Combustion of Kerosene

$2C_{12}H_{26}$	+	$37O_2$	→	$24CO_2$	+	$26H_2O$
kerosene		oxygen		carbon dioxide		water

Explain that a fair comparison of the combustion chemistry of ethanol and kerosene would show the same number of fuel molecules in each equation. The standard way to accomplish this is to write each equation using 1 as the coefficient for the fuel molecule. To do this, divide each coefficient in the kerosene combustion equation by 2, which results in Equation 3.

Equation 3 Simplified Equation for the Complete Combustion of Kerosene

$C_{12}H_{26}$	+	$18.5O_2$	→	$12CO_2$	+	$13H_2O$
kerosene		oxygen		carbon dioxide		water

Point out that this standardizing procedure results in a coefficient of 18.5 for O_2, which may be confusing to students because half of a molecule cannot exist. Nonetheless, many chemical equations are written with fractional coefficients for comparison purposes. You may also wish to point out that the coefficients of a chemical equation represent ratios of quantities of molecules of the various substances involved in the reaction, rather than individual atoms or molecules.

7. Discussing the role of chemical structure in determining the energy of combustion

Review Activity 31.1 by returning to the models of kerosene and ethanol. Have students consider how the combustion reaction with oxygen gas gets started. Remind them that in nature the reaction is brought about by the addition of a small amount of energy, called the activation energy. Activation energy is the minimum amount of energy required to initiate a reaction. For instance, the energy from a match makes air molecules move faster through space. When the molecules move faster, they collide more often and are more likely to react. When oxygen molecules react with fuel molecules to form carbon dioxide and water, we call the process combustion or burning.

Ask students to turn to Activity 31.3, "Combustion," and have them read the Purpose and Introduction. Distribute the molecular model sets. Encourage and assist students as they complete the Procedure. The equations describing the complete combustion reactions modeled in Activity 31.3 are shown in Table 3.

Table 3 Combustion Reactions of Four Organic Compounds

Compound	Combustion Equation	Heat of Combustion (kcal/g)
Methane	$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$	13.3
Ethanol	$C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$	7.11
Benzene	$C_6H_6 + 7.5O_2 \rightarrow 6CO_2 + 3H_2O$	10.0
Hexane	$C_6H_{14} + 9.5O_2 \rightarrow 6CO_2 + 7H_2O$	13.8

Teacher's Note: These equations are written to compare the combustion of equal numbers of molecules of each of the four hydrocarbons. This results in a fractional coefficient for O_2 in the equations involving benzene and hexane. The values given for the energy released during combustion are the number of kilocalories generated during the combustion of 1 gram of each substance. If you have already introduced the concept of a mole, this is a good opportunity to reinforce its use by having students calculate the molar heat of combustion. An understanding of moles is not necessary to complete this or any Science and Sustainability activity.

When students finish the Procedure, encourage them to work in their groups on the Group Analysis Question.

Group Analysis Question (31.3)

1. *The incomplete combustion of methane (CH_4) produces carbon monoxide (CO), carbon dioxide (CO_2), and water (H_2O). Write a balanced chemical equation for this reaction. (Hint: Try starting with more than one methane molecule.)*
   Help students set up the reactants and products as shown below.

$$\_\_\_ CH_4 + \_\_\_ O_2 \rightarrow \_\_\_ CO + \_\_\_ CO_2 + \_\_\_ H_2O$$

   There are a number of ways to balance this equation, depending on the ratio of carbon monoxide to carbon dioxide.

$$\_\_\_ \quad \_\_\_ \quad \_\_\_ \quad \_\_\_ \quad \_\_\_$$

In fact, combustion in air generally produces much more carbon dioxide than carbon monoxide. Incomplete combustion will be more fully addressed in Activity 36.

Allow students time to work on the Individual Analysis Questions, and then discuss their responses.

Individual Analysis Questions (31.3)

2. *Draw structural formulas for the reactant and product molecules you constructed in Procedure Step 1.*
   See Table 4.

Table 4 Structural formulas for reactants and products of methane combustion

Standard Chemical Formula	Sketch of Molecule
CH_4	
O_2	
CO_2	
H_2O	

3. a. *Find the molecular mass for each of the reactant molecule(s) you drew for Analysis Question 2.*
   b. *Find the molecular mass for each of the product molecule(s) you drew for Analysis Question 2.*

c. Calculate the total mass of all the reactant molecules in your balanced equation from Procedure Step 1.

d. Calculate the total mass of all the product molecules in your balanced equation from Procedure Step 1.

e. Write a sentence comparing the total mass of the products to that of the reactants.

Formula mass was introduced in Activity 15, "Classifying Elements," but students may need to be reminded of how to calculate it. Calculations are shown in Table 5, below.

Knowledge of how to perform this calculation is important in helping students connect the ideas of conservation of matter and conservation of atoms with the idea of conservation of mass. Previously, students noticed that the number of atoms in the reactants and the number of atoms in the products are the same. Now they see that the mass of the reactants and the mass of the products are also the same.

4. What is the source of the energy released during combustion?

When a hydrocarbon is burned, energy is

Table 5 Formula Mass Calculations

	Reactants				Products			
	CH_4		$2O_2$		CO_2		$2H_20$	
Formula Mass	C		O		C		H	
	H	—			O	—	O	—

5. ***Use your knowledge of chemistry to rank four hydrocarbon molecules—methane, ethanol, benzene, and hexane—according to which releases the most energy during combustion. Explain your reasoning.***

   The amount of energy released by 1 gram

Extensions

1. Have students compare their results from Activity 31.1 to the theoretical values shown on Transparency 31.2. The SEPUP data given in Table 2 on page 800 result in values for ethanol of 3,280 cal/g and for kerosene of 5,706 cal/g. The accepted theoretical value for the heat of combustion of kerosene is 11,000 cal/g, and that for ethanol is 7,100 cal/g. Classroom values are significantly lower than the accepted values, primarily because of the large heat loss to the environment that occurs in the classroom experiment. Nonetheless, it is possible to do a relative, rather than a direct, comparison of the accuracy of the classroom data. The ratio of the theoretical heat of combustion of kerosene to ethanol is:

$$\frac{11{,}000}{7{,}100} = 1.5$$

the ratio of the SEPUP values for the heat of combustion of kerosene to ethanol is:

$$\frac{5{,}700}{3{,}300} = 1.7$$

Students can then calculate the percent error of both the actual values and the ratio:

$$\text{percent error} = \frac{(\text{experimental value}) - (\text{theoretical value})}{(\text{theoretical value})} \bullet 100$$

Calculations using the SEPUP data are shown here.

For kerosene:

$$\text{percent error} = \frac{(5{,}706\text{ cal}) - (11{,}000\text{ cal})}{(11{,}000\text{ cal})} \bullet 100$$

$$\text{percent error} = -48\%$$

For ethanol:

$$\text{percent error} = \frac{(3{,}280\ \text{cal}) - (7{,}100\ \text{cal})}{(7{,}100\ \text{cal})} \cdot 100$$

$$\text{percent error} = -54\%$$

These errors are very high because there is so much heat "lost" to the environment in this investigation. The error values are negative because the experimental values were lower than the theoretical values. However, comparing the two fuels shows that a similar proportion of the heat was "lost" in each case. This comparison can be performed quantitatively by comparing the ratio of theoretical values for the heats of combustion of the two fuels to the ratio of experimental values, as shown here:

$$\text{percent error} = \frac{(1.7) - (1.5)}{(1.5)} \cdot 100$$

$$\text{percent error} = 13\%$$

You may want to relate these data to the types of errors discussed in Analysis Question 1 in Activity 31.1.

2. Encourage students to investigate the historical basis for the relationship between automobile engine efficiency and mileage. Specifically, as changes occurred in engine efficiency, what changes also occurred in gasoline import policy, availability, and taxation?
3. Assign students to research the health risks associated with the production of CO from incomplete combustion in cars, stoves, and other combustion applications.

Class Data Table from Activity 31.1

Group	Kerosene		Ethanol	
	cal / g	cal / mL	cal / g	cal / mL
1				
2				
3				
4				
5				
6				
7				
8				

Comparison of Fuel Properties

Property	Methanol	Ethanol	Gasoline (87 Octane)	E85
Chemical formula	CH_3OH	C_2H_5OH	C_4 to C_{12} chains	85% ethanol 15% gasoline
Main constituents (% by weight)	38 C, 12 H, 50 O	52 C, 13 H, 35 O	85–88 C, 12–15 H	57 C, 13 H, 30 O
Heat of combustion (calories / gram)	5,300	7,100	10,000–10,560	6,950
Approx. ignition point temperature	425°C	450°C	250°C	400°C
Miles per gallon as compared to gasoline	55%	70%	100%	72%
Relative tank size to yield equivalent driving range	1.8 times larger	1.5 times larger	standard	1.4 times larger
Cold weather starting	poor	poor	good	good
Change in power	+4%	+5%	standard	+3–5%

* Depends on percentage and type of hydrocarbon fraction

Some Common Fuels

Substance	State	Heat of Combustion (cal / gram)
hydrogen	gas	29,200
paraffin wax	solid	13,000
methane	gas	13,000
ethane	gas	12,000
propane	gas	11,900
butane	gas	11,800
pentane	gas	11,500
hexane	liquid	11,500
n-octane	liquid	11,500
gasoline	liquid	11,500
kerosene	liquid	11,000
fats, animal	liquid	9,500
olive oil	liquid	9,400
butter	liquid	9,200
charcoal	solid	8,100
n-propanol	liquid	8,000
iso-propanol	liquid	7,900
ethanol	liquid	7,100
methanol	liquid	5,300
pine wood	solid	4,400
sucrose	solid	3,900

Name ______________________________ Date ____________

How Much Energy Is There?

Purpose

Determine which of two fuels—kerosene or ethanol—releases more energy as it combusts. Decide which fuel is better for use in automobiles and identify the trade-offs in attempting to create the perfect fuel.

Introduction

All human activity requires energy—from sleeping to constructing roads and buildings, from watching television to generating electricity. In this activity, you will explore combustion reactions. Combustion, commonly called burning, is the source of much of the energy we use for transportation, cooking, heating, generating electricity, and other activities. Combustion also produces chemical products, some of which are pollutants. Two commonly combusted fuels are kerosene, which is a petroleum product, and ethanol, which is an alcohol often produced from crops. You will burn each of these fuels to compare the amount of energy released and some of the chemical wastes produced.

Prediction

Which fuel—kerosene or ethanol—do you think will release the most energy when it combusts? Explain your reasoning.

Materials

For each group of four students

- 1 glass fuel burner containing either kerosene or ethanol
- 1 can holder (for soda can)
- 1 immersion thermometer
- 1 book of matches
- 1 balance
- 1 100-mL graduated cylinder
- 1 metric ruler
- access to a clock with a second hand
- access to water

For each team of two students

- 1 aluminum soda can
- 1 calculator (optional)

For each student

- 1 pair of safety glasses

Safety Note

Exercise extreme caution when using an open flame in the classroom. Be sure you know how to extinguish the burner and where to find a fire blanket or fire extinguisher to put out any accidental fires. Always wear safety glasses during this activity, and wash your hands before leaving the lab.

Continued on next page

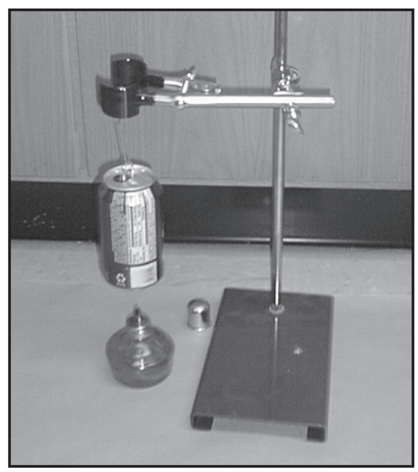
Name ______________________________ Date ____________

How Much Energy Is There? (cont.)

Procedure

Part A Carrying Out the Investigation

Figure 1 Suspending the Soda Can Above the Fuel Burner



Continued on next page

Name ______________________________ Date ____________

How Much Energy Is There? (cont.)

Procedure
(cont.)

Table 1 Combustion of ____________

Part B Analyzing the Data

Continued on next page

Name ______________________________ Date ____________

How Much Energy Is There? (cont.)

Procedure (cont.)

Table 2 Comparison of Two Fuels

	Kerosene	Ethanol
Average mass of fuel combusted (g)		
Density of fuel (g/mL)	0.82	0.79
Average volume of fuel combusted (mL) V = mass/density		
Average energy absorbed by the water (cal) $E = mass_{water} \times \Delta T_{water} \times Cp_{water}$		
Average energy content of fuel (cal/g)		
Average energy content of fuel (cal/mL)		

Analysis

Group Analysis

1. The results of any experiment may be affected by a variety of errors. Errors can often account for variations in data. Identify some potential sources of error in this experiment that may have affected your results.

2. The energy content of a fuel can be measured as the amount of energy per mass (cal/g or J/g) or the amount of energy per volume (cal/mL or J/mL). Which of these measures of energy content do you think is more useful when comparing fuels? Explain your reasoning.

Individual Analysis

3. Gasoline is chemically very similar to kerosene. How could the results of this experiment affect your decision to buy fuel for your car that contains ethanol rather than pure gasoline?

4. If you were considering the use of one of these fuels for your car, what other information would you like to have before deciding which to use?